

EAS thermal neutron lateral and temporal distributions

YU.V.STENKIN¹, D.M.GROMUSHKIN², A.A.PETRUKHIN², O.B.SHCHEGOLEV¹, V.I. STEPANOV¹,
V.I.VOLCHENKO¹, I.I. YASHIN² AND E.A. ZADEBA².

¹ *Institute for Nuclear Research of Russian Academy of Sciences, Moscow*

² *National Research Nuclear University MEPhI, Moscow*

yuri.stenkin@rambler.ru

Abstract: A novel type of EAS array (PRISMA-32) has been constructed on the base of NEVOD-DECOR experiment (MEPhI, Moscow) and is now taking data. It consists of 32 specially designed scintillator en-detectors able to measure two main EAS components: hadrons (n) and electrons (e). First results on thermal neutron lateral as well as temporal distributions are presented. Obtained exponential neutron lateral distributions are consistent with that expected for normal hadron production with exponential transverse momentum distribution. As there are no other experimental data on thermal neutron distributions and so, to compare results with other measurements, we additionally obtained electron lateral distribution function (using the same detectors) and compared it with NKG - function. Recorded neutron temporal distributions are very close to that obtained with data of our previous prototypes.

Keywords: EAS, neutrons, en-detector, distributions

1 Introduction

An idea of a novel type of EAS array proposed for the first time in 2001 [1] was developed later [2, 3] to the PRISMA (PRImary Spectrum Measurement Array) project. The main feature of the array is the ability to measure the main EAS component - hadrons, through the measurement of secondary thermal neutrons produced by these hadrons. Special inorganic scintillator detector (en-detector) has been developed for this purpose. The main feature of the detector is sensitivity to two EAS components: hadrons - the main one and electrons - the most numerous one. A prototype of such array consisting of 32 en-detectors (PRISMA-32) is running now in Moscow on the base of the NEVOD-DECOR experiment (MEPhI). It started in February 2012. Details of the en-detector design and of the PRISMA-32 array can be found elsewhere [4, 5].

2 Data acquisition and pre-analysis

32 en-detectors array (composed of two 16-detector clusters) is located inside the experimental hall situated on the 4th floor of the NEVOD building in MEPhI. Thin layer (~ 30 mg/cm²) of special inorganic scintillator ZnS(Ag) + ⁶LiF of 0.36 m² area is placed at the bottom of cylindrical polyethylene (PE) 200-liter tank which is used as the detector housing. A 5"-PMT (FEU-200) is mounted on the tank lid. Light reflecting cone made of foiled PE foam of 5-mm thickness is used for better light collection. As a result, we collect ~ 50 -100 photoelectrons per a neutron capture. All pulses are integrated with the time of 1 μ s. FADC (ADLINK 10 bit PCI slot PCI-9810) is used for pulse shape digitizing (20000 samples with a step of 1 μ s). First pulse produced mostly by EAS electrons is used for energy deposit measurements and delayed neutron capture pulses are counted within a time gate of 20 ms to give the number of neutrons. The detector layout is shown in figure 1. Unfortunately, we were pressed to use free space around

the water pool and this resulted in not uniform array structure. Clusters P1 and P2 are not identical in shape but they have identical independent data acquisition systems. The first level trigger is very simple: a coincidence of any 2 from 16 detectors in a time gate of 1 μ s starts all FADCs. On-line program analyzes the data and produces second level triggers: M1 in a case of coincidences above threshold of ~ 5 m. i. p. (minimum ionizing particle) in the first time bin, M2 in a case of total energy deposit more than 50 particles, and M3 if the number of recorded neutrons is more than 4. We use 2 signals from each detector (from the last 12th dynode and from the 7th dynode) to make dynamic range as wide as possible. All pulses are digitized. Clocks of both systems are synchronized and the data are combined off-line using the time gate of 20 ms. As a result, we have data only in a case when at least 2 detectors were hit with energy deposit threshold of ~ 5 m. i. p. in each cluster (4-fold coincidence in total), or when energy deposit exceeded 50 m. i. p. in each cluster, or the number of recorded neutrons exceeded 4 in each cluster. Note that en-detector counting rate is very low (~ 0.5 s⁻¹) and thus probability of chance coincidence inside 1 μ s for 1 cluster is $\sim 0.5 \times 16 \times 10^{-6} = 8 \times 10^{-6}$. Counting rate of real triggers of a cluster is ~ 700 per day. Therefore, probability of chance coincidence between the 2 cluster triggers is $\sim 700/86400 \times 0.02 = 1.4 \times 10^{-4}$. In addition to the physical triggers, every 5 min the program generates a soft trigger M0 to measure and to monitor chance coincidence level for neutron detection. The latter was found to be 0.34 per event.

3 Results

In this report we present experimental data on the "neutron vapor" parameters obtained up to date. The thermal neutron lateral distribution in events selected by M1 trigger and 8-fold coincidence with at least 15 m. i. p. in each detector is shown in figure 2. As one can see, the measured time distribution is fitted very well by the two-

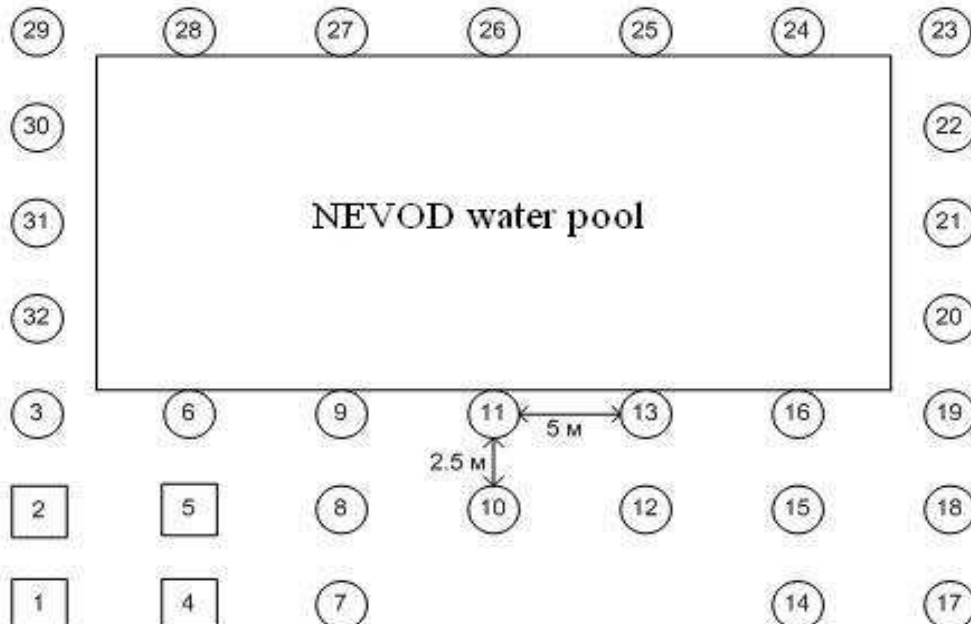


Fig. 1: PRISMA-32 lay-out. Detectors 1, 2, 4 and 5 are of square shape 0.75 sq. m each; others - cylindrical 0.36 sq. m. Detectors 1 – 16 compose cluster P1, and detectors 17 – 32 compose cluster P2.

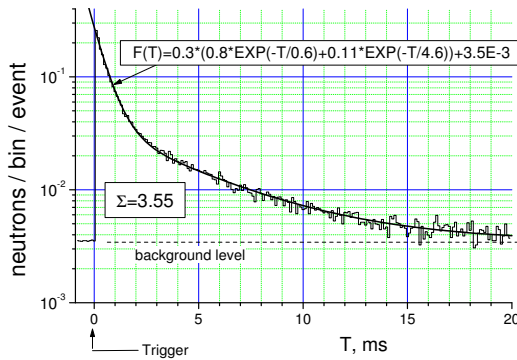


Fig. 2: EAS thermal neutron time distributions measured by PRISMA-32. $T=0$ corresponds to the trigger position (EAS passage), Σ shows the mean total number of recorded neutrons per event.

exponential function as it was shown in our previous works [6, 7]. The first time component is close (but not equal to) to 1 ms as expected for the thermal neutron lifetime in rock, soil or concrete. This so-called local neutron component is produced by high energy hadrons in the concrete floor in a vicinity of the detector. The second time component could be explained by an admixture of the neutrons produced in the thick concrete roof and neutrons produced in the atmosphere introduced in earlier our works [2-4]. Atmospheric neutrons are produced in air at distances less or about one hadronic interaction length (~ 750 m at sea level) above the detectors and was expected

to have rather large delay. First measured time parameter less than it could be expected. Why? In our opinion, the first parameter is equal to only 0.6 ms due to the influence of the NEVOD water pool. It is known that neutron lifetime in water is ~ 0.2 ms, i.e. much less than in soil. That is why a presence of water must decrease the lifetime of recorded neutrons. As for the second time parameter, it is much less than it is expected for atmospheric neutrons. The PRISMA-32 array is located inside the building having rather thick concrete walls and roof (from 20 to 50 cm). Therefore, it is difficult for atmospheric thermal neutrons to penetrate the experimental hall. On the other hand, the roof and the walls serve as an additional targets for hadron interactions and as a moderator and a thermalizer for fast neutrons. As a result, thermal neutrons from the roof and the walls must have an additional delay to reach the detector (~ 0.5 ms/m). Taking into account that the height of the roof is $\sim 7-8$ m above the detectors, one could expect the delay of ~ 4 ms. So, in our opinion, the second observed time parameter is probably explained mainly by the concrete roof and walls.

EAS thermal neutron lateral distribution is presented in figure 3 along with a fitting function. Here again double exponential function fits the data rather well. The first distance parameter (1 m) is probably connected with the characteristic distance between recorded neutron and its parent hadron. In other words, recorded thermal neutrons produced locally (local neutrons) are collected from the nearest vicinity of the detector. Keeping this in the mind one can conclude that the second distance parameter (11 m) is connected with the EAS hadron lateral distribution following the exponential distribution in transverse momentum. It is obvious that a hadron with momentum P_h produced at one interaction length above the observa-

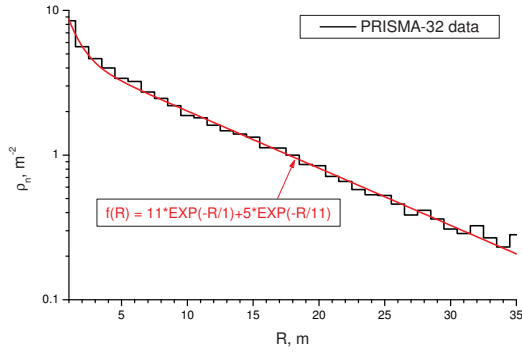


Fig. 3: EAS thermal neutron lateral distribution. R - distance from the EAS core.

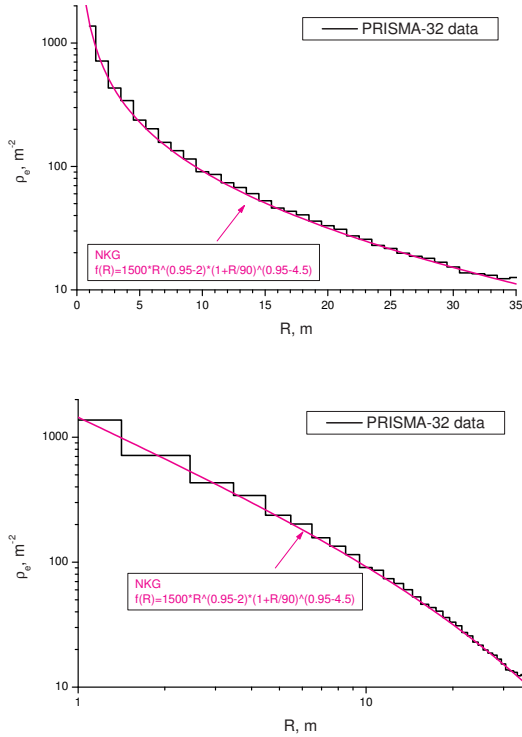


Fig. 4: Electron lateral distribution measured by the PRISMA-32 with the en-detectors. Upper panel: Linear - Log scale; Lower panel: Log - Log scale.

tional level (ΔH) with a transverse momentum P_t (note that $\langle P_t \rangle \approx 0.4 \text{ GeV}/c$) could be found at a distance R from the EAS axis:

$$R = \Delta H \times P_t / P_h \quad (1)$$

It is also possible to estimate from (1) the mean energy of hadrons (mean momentum) producing the recorded neutrons as: $\langle P_h \rangle \approx \Delta H \times \langle P_t \rangle / R = 750 \times 0.4 / 11 \approx 27 \text{ GeV}/c$. To compare our results with other measurements, we additionally obtained electron lateral distribution function (using the same en-detectors) and compared it with NKG - function. Experimental results along with fitting functions are shown in figure 4 in linear (left panel) and logarithmic (right panel) R -axis scale. These data also

were selected by M1 with 8-fold coincidence with 15 m. i. p. threshold. It is seen that NKG power law function can fit the data very good but with the abnormally small age parameter $s = 0.95$. Probably this is also due to the roof presence.

4 Conclusion

A novel method of EAS study has been developed, detector prototype PRISMA-32) has been realized and operates now. The measured parameters of EAS neutrons time and lateral distributions are close but not equal to our initial expectations. Location of the array inside the building does not probably allow us to record atmospheric neutrons, i. e. neutrons born in the atmosphere. Measured electron lateral distribution at distances 1-30 m seems to be fitted good with the NKG-function with age close to 1. Results of this work and [8] will help us to optimize the future full-scale PRISMA array's design.

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